



EMBEDDED  
OPEN SOURCE  
SUMMIT

# Reproducible System Composition –

## Combining Linux, Xen & Zephyr on One Embedded Hardware

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@ProjectElisa

#EMBEDDEDOSSUMMIT

*“The mission of the project is to define and maintain a common set of elements, processes and tools that can be incorporated into Linux-based, safety-critical systems amenable to safety certification.”*



*“The scope of the project includes software and documentation development under an OSI-approved license supporting the mission, including documentation, testing, integration and the creation of other artifacts that aid the development, deployment, operation or adoption of the project.”*



from the [technical charter](#)

Premier  
Members



General  
Members



Associate  
Members



Industry  
Support



# Working Groups (WGs) - Horizontal



Safety Architecture



**Red Hat**



Open Source  
Engineering Process

**CodeThink**



Linux Features

**m** mobileye™ / **intel**®



Systems



**BOSCH**



Tool investigation &  
Code Improvement



Elektrobit

**CodeThink**

# Working Groups (WGs) - Verticals



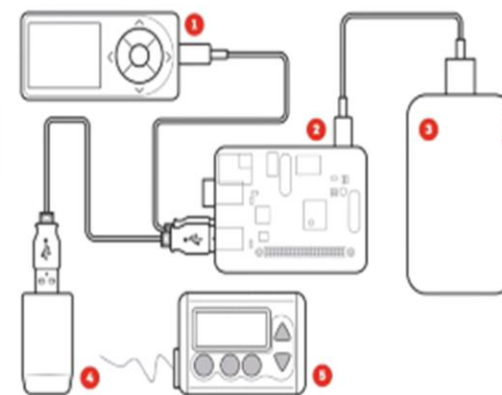
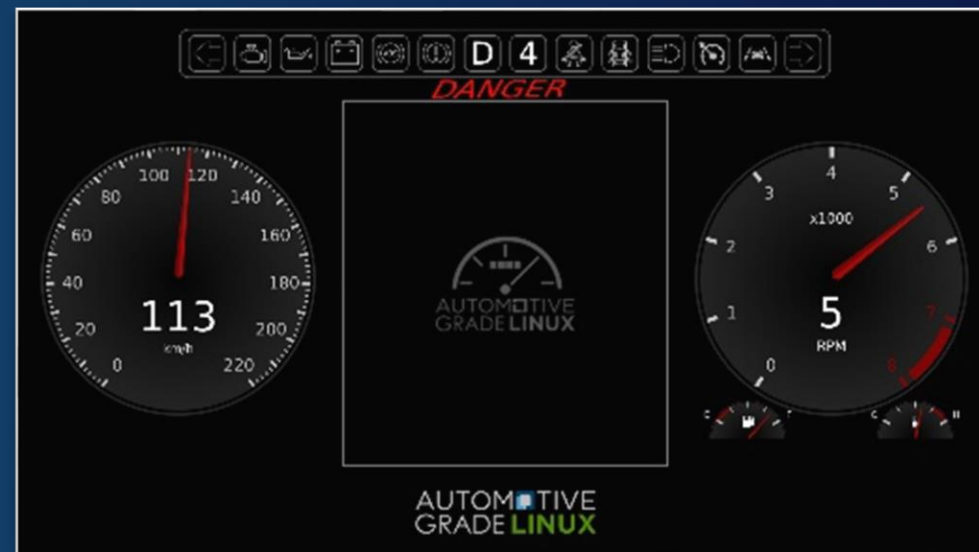
Aerospace <sup>New!</sup>



Automotive



Medical Devices



## OpenAPS elements

1. Continuous glucose monitor
2. Computer
3. Battery
4. Radio stick
5. Insulin pump

@DanaMLewis

Dana Lewis' OpenAPS project: <https://youtu.be/kgu-AYSnyZ8>



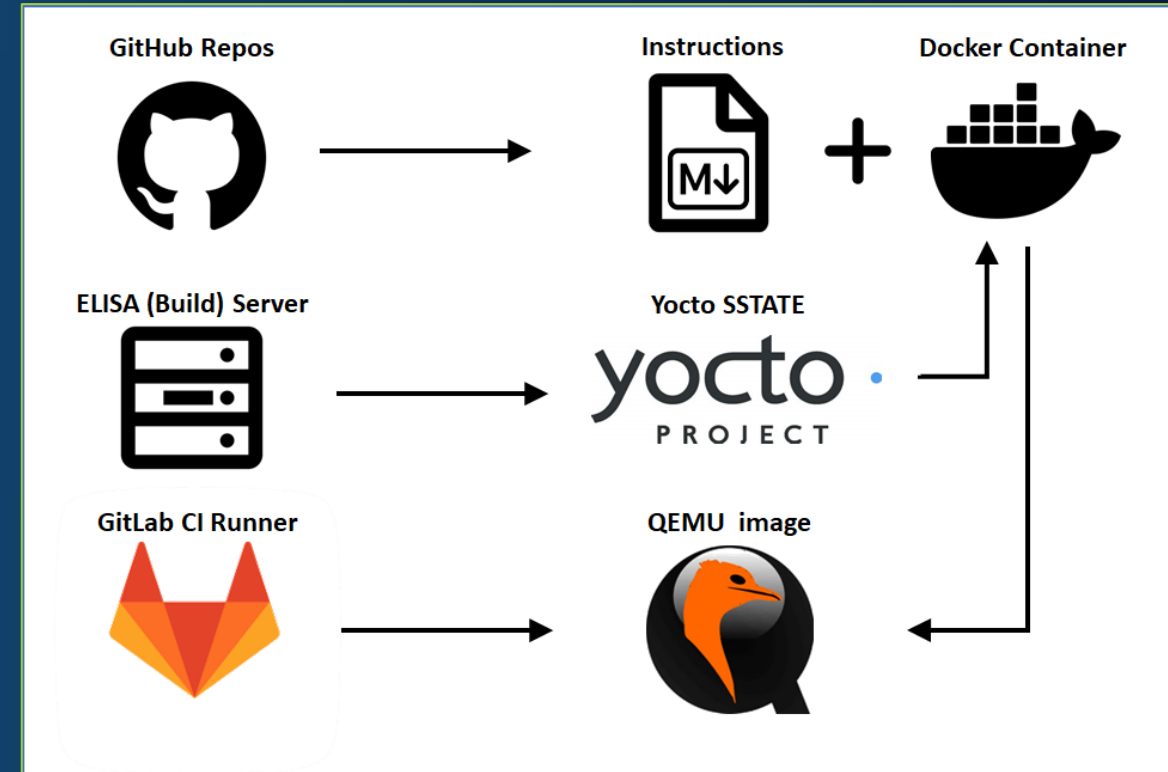
**LESS**

**I \$**

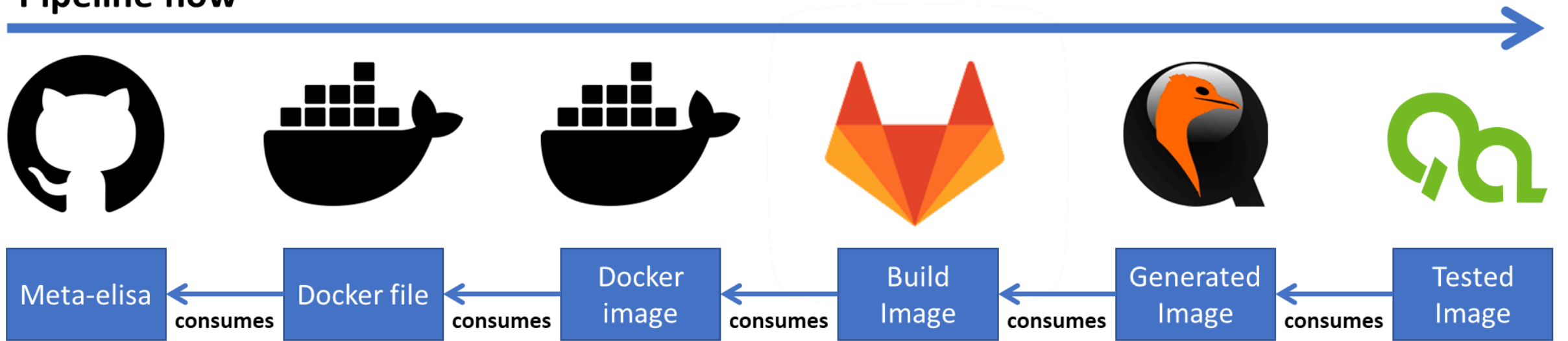
**MORE**

# meta-elisa: Various starting points provided

- Plain and native from source  
<https://github.com/elisa-tech/meta-elisa>
- Using docker container  
[https://github.com/elisa-tech/wg-automotive/tree/master/Docker\\_container](https://github.com/elisa-tech/wg-automotive/tree/master/Docker_container)
- With cached build using SSTATE  
[modify "conf/local.conf" after the "source" command before the "bitbake" command](#)
- Download binaries directly from build server  
<https://gitlab.com/elisa-tech/meta-elisa-ci>



## Pipeline flow



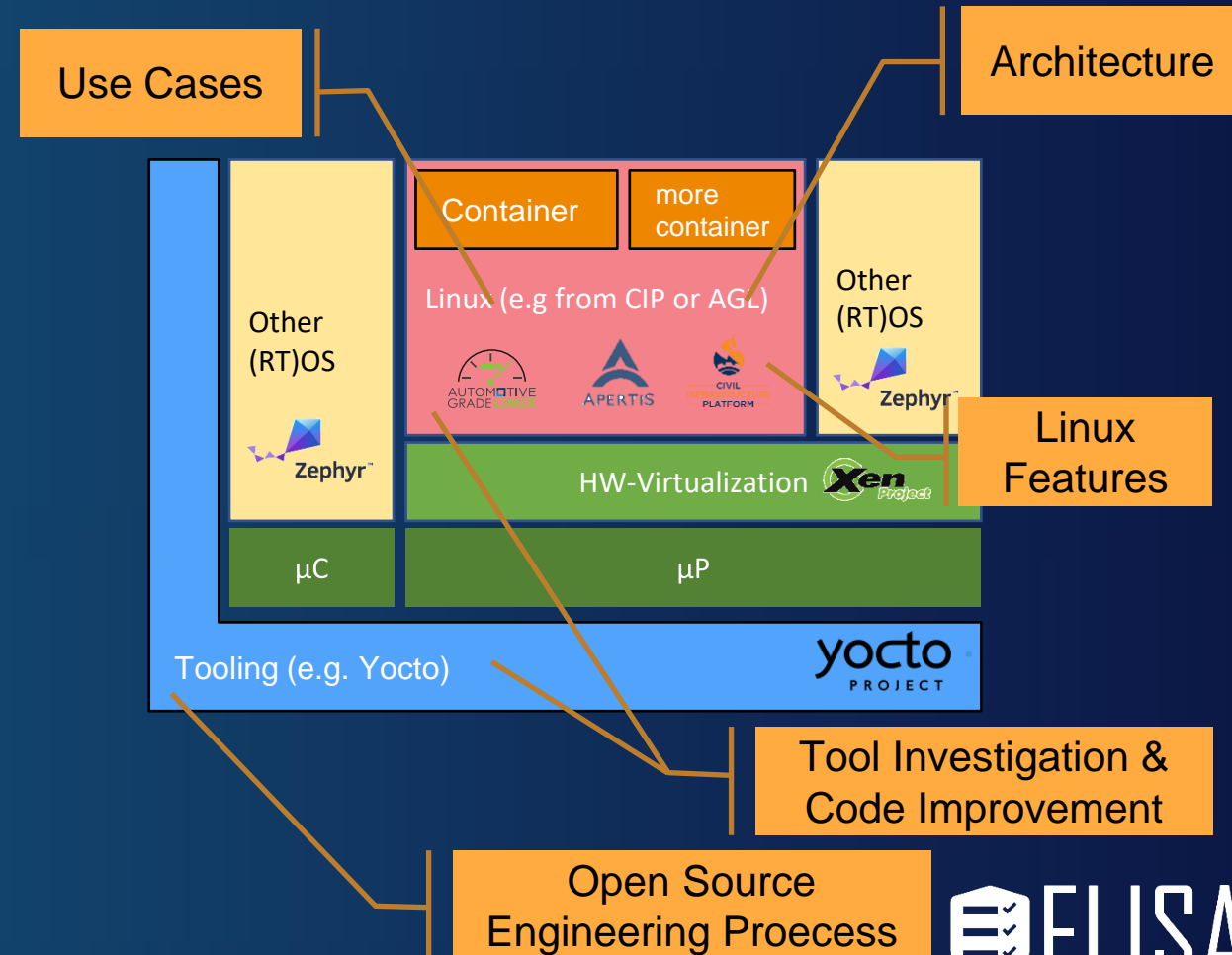
*Full description in the blog*

<https://elisa.tech/blog/2023/04/05/elisa-ci-enablement-automation-tools-for-easier-collaboration/>



# ELISA Working Groups - Fit in an exemplary system

- **Linux Features, Architecture and Code Improvements** should be integrated into the reference system directly.
- **Tools and Engineering process** should serve the reproducible product creation.
- **Medical, Automotive, Aerospace** and future WG use cases should be able to strip down the reference system to their use case demands.



# Interaction with other communities (outside of ELISA)

- Open source projects focusing on safety-critical analysis



- Open source projects with safety-critical relevance and comparable system architecture considerations



- Further community interactions

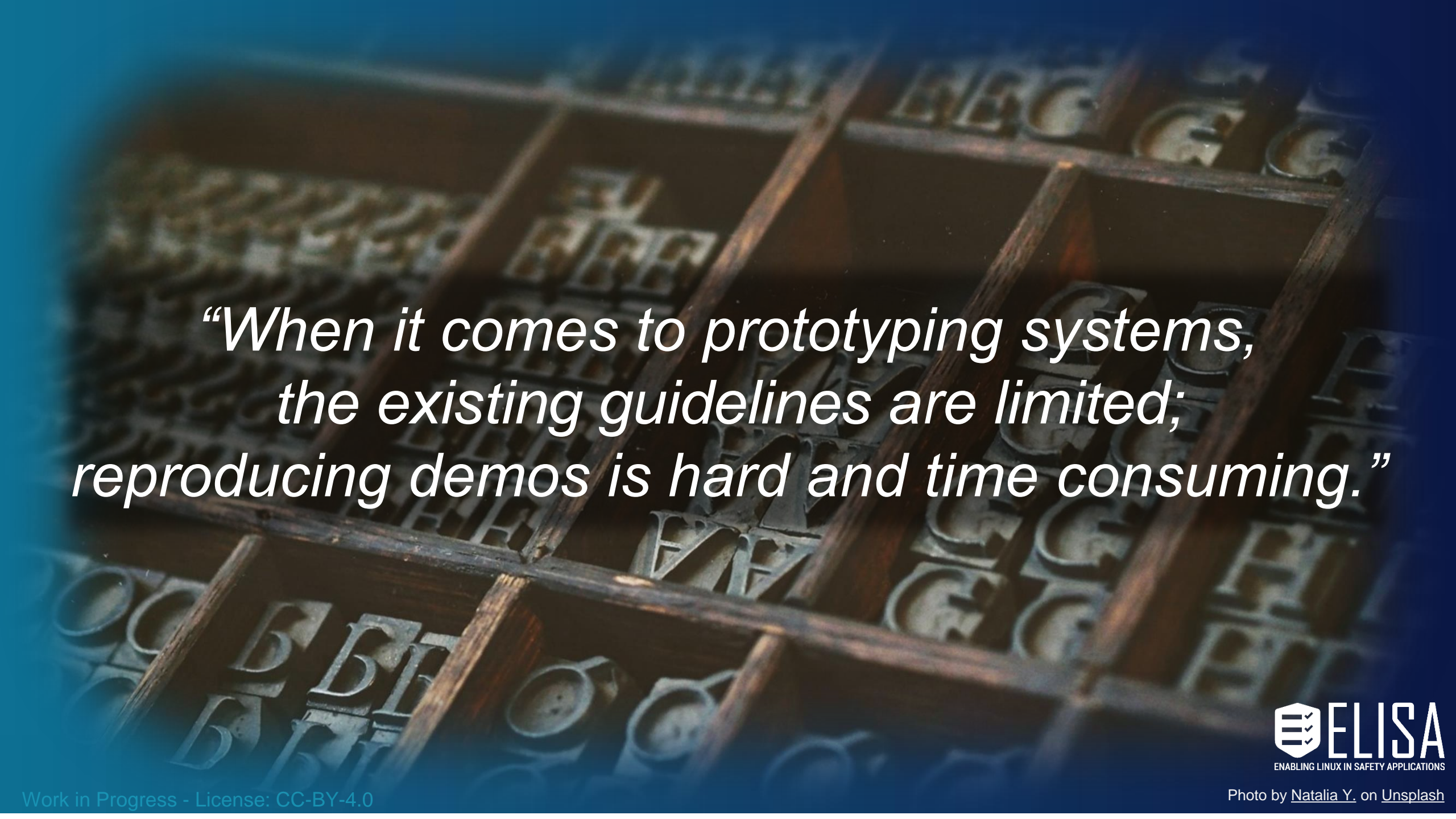


*"If you have an apple and I have an apple and we exchange these apples then you and I will still each have **one apple**.*

*But if you have an idea and I have an idea and we exchange these ideas, then each of us will have **two ideas**."*

— George Bernard Shaw





*“When it comes to prototyping systems,  
the existing guidelines are limited;  
reproducing demos is hard and time consuming.”*





# Static Partitioning with Xen, LinuxRT, and Zephyr: a concrete end-to-end example

Stefano Stabellini  
Embedded Linux Conference 2022

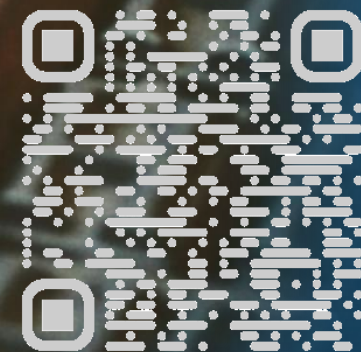


Photo by [Natalia Y.](#) on [Unsplash](#)





*“A product will run on real hardware.”*

# Major problems to setup XEN systems

- Select target board with
  - Hardware support for XEN, especially SMMU controller
  - XEN community support
  - Documentation for build and setup
  - Licenses compliant to OSS project
- Setup of Yocto build environment
  - Amount of computer resources
  - Network and Host dependencies
- Finding valid descriptions
- Build image parts based on descriptions
- Finding community support at occurring build problems
- Understanding XEN setup and structure



# Evaluated targets

- Renesas RCAR 3.0 family ([link](#) to Wiki of eLinux)
  - + XEN hardware support
  - + Functional XEN systems (also graphic)
  - - Proprietary licenses for essential parts like graphic
  - - Not available at standard market
- Xilinx Zynqmp and Ultrascale family ([link](#) to product page)
  - + XEN hardware support
  - + Functional XEN systems
  - + Good documentation and open source support of Xilinx
  - - Zcu102 well supported, but additional complexity due to FPGA programming
  - - Graphic at Zcu102 atm not able to be handled by XEN

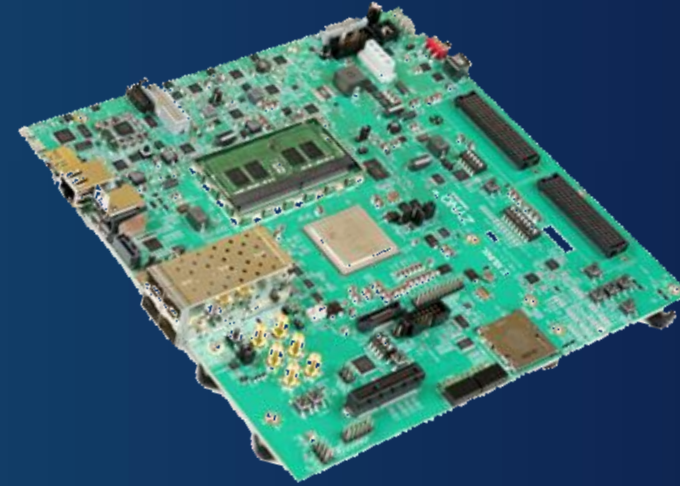


# Evaluated targets

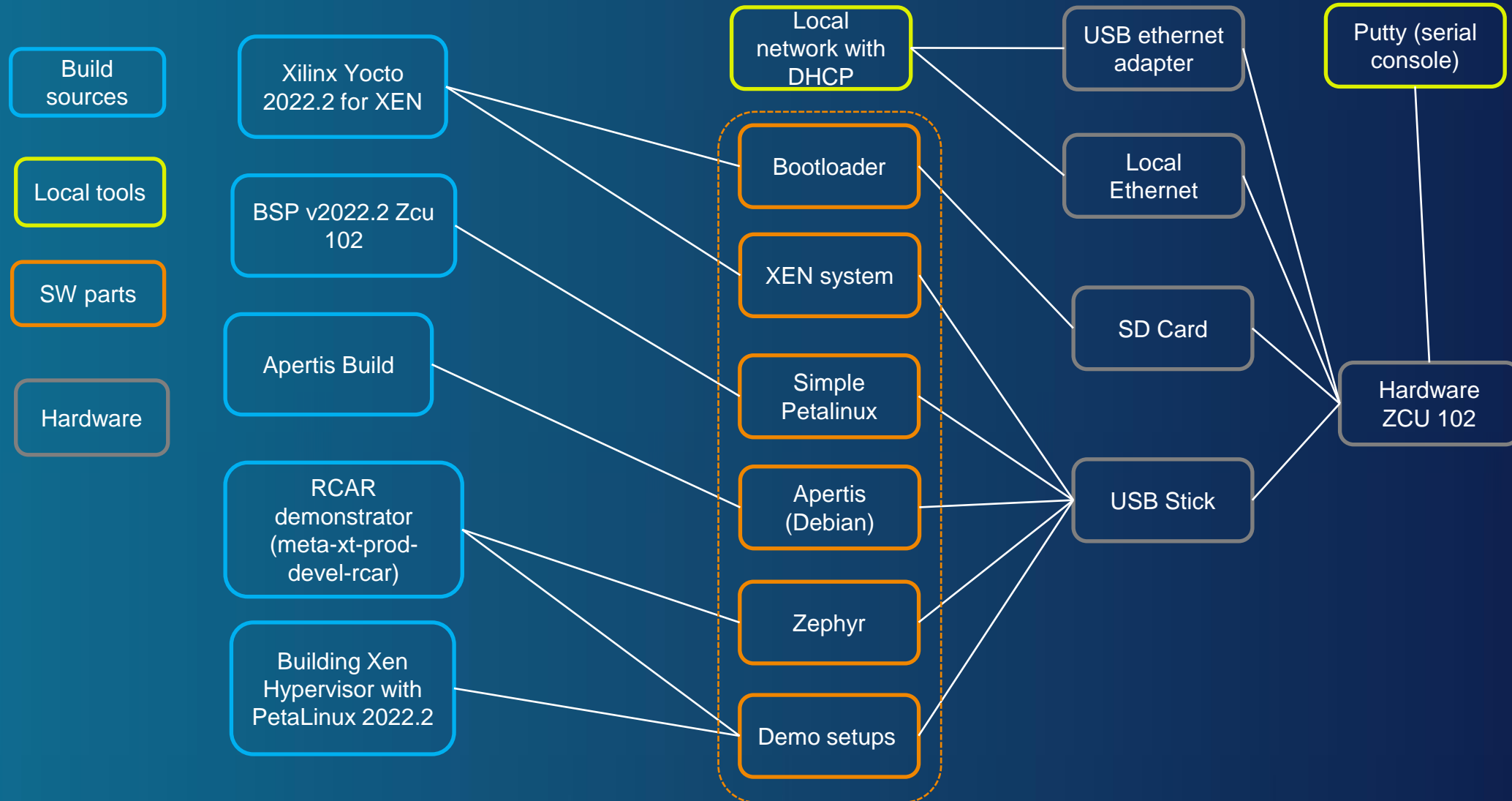
- Qemu systems for Xilinx ([link](#) with some hints for setup with XEN at Xilinx boards)
  - + XEN support
  - + Functional XEN systems
  - + no hardware needed
  - - Only for development, not for hardware related demo cases
- Raspberry Pi systems
  - - Hardware support not sufficient for security requirements of XEN
- NXP Imx.8 systems
  - + Good hardware support for hypervisor like XEN
  - - Less community support

# Used hardware

- Board ZCU102 ([link](#) to description)
  - Reference manual ([link](#))
  - SD card 16GB for boot loader
  - USB Stick 16GB for demonstrator setup
  - USB-Ethernet-Adapter (DLINK)
- Environment for setup
  - Local DHCP server (VM with system networkd)
  - Putty for serial console
  - USB Keyboard (for TTY console)
  - HDMI screen



# Overview to XEN demonstrator



# Development steps

- Setup of Yocto environment
  - Native build dependent on Linux system
  - Better: Docker image to build ([link](#) to build description)
- Work with system image files, not directly with SD cards or other media
- Build XEN images at Yocto environment
- Get BSP with prebuilt images from Xilinx (also other systems are possible for DomU)
- Create system images with Xilinx compliant scheme
- Copy files for XEN Hypervisor to image file
- Create fitting boot scripts with XEN image builder
- Start XEN and Domain-0 and check system access to USB, Ethernet and SD card
- Create XEN configuration files for XEN demonstrations and setup related binaries
- Test XEN demonstrations

# System images for SD card and USB stick

- Scheme
  - MSDOS partition scheme
  - Boot partition (fat)
    - Boot.bin (Boot loader (U-Boot) and FPGA stream)
    - Files for XEN Hypervisor (Domain-0) (Ramdisk)
    - Files for DomU (Petalinux, Zephyr, Apertis) (Ramdisk)
    - XEN configuration files to demonstrate DomU setups
    - Boot scripts to start customized Domain-0
  - Data partition (ext4)
    - /etc to make configuration of Domain-0 persistent
  - Root file system partition of some DomU (ext4)



# External parts of system images

- Xen Hypervisor ([link](#) for build description)
  - Image, ramdisk, device tree
  - Boot.bin
- Petalinux ([link](#) for binaries from "BSP")
  - Image, ramdisk, (device tree: not used for XEN)
- Zephyr (atm got from Demo for Renesas RCAR, [link](#) for build description)
  - Image
  - Configuration file for XEN
- XEN configuration files (created on description at [link](#))
- Apertis (Debian based, specific image, but general build instructions at [link](#))
  - Image, ramdisk, (device tree: not used for XEN)
- XEN image builder ([link](#) for download and usage)

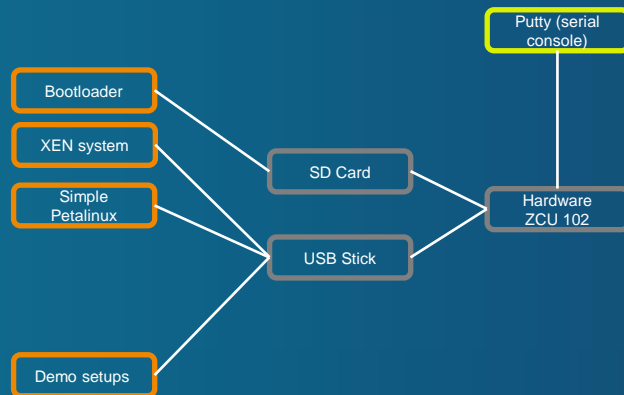
# Overview to XEN demonstrations

- Simple: DomU with Petalinux as ramdisk image, no additional devices
- Zephyr: DomU with simple Zephyr application (2 tasks), no additional devices
- Apertis: DomU with small Apertis system as ramdisk image, no additional devices
- Paravirtualized network: DomU with Petalinux as ramdisk image, additional NET interface
  - Shell script to create network bridge at Domain-0
- Paravirtualized block device: DomU with Petalinux, booted from paravirtualized block device
  - Partition 3 used to boot the system
- Passthrough of SD card controller: DomU with Petalinux as ramdisk image, additional block device
  - Domain-0 has to be started with "passthrough" option of SD card controller
- Passthrough of ethernet controller: DomU with Petalinux as ramdisk image, additional network interface
  - Domain-0 has to be started with "passthrough" option of ethernet controller

# Simple:DomU with Petalinux as ramdisk image, no additional devices

- Starting with bootloader
- Booting with XEN and **Domain-0**
- Check list of started Domains
- Starting "Simple" demo with Petalinux ramdisk image
- Switch console to **Guest0**
- No Network interfaces
- No block devices but ramdisks
- Getting back console to **Domain-0** (XEN)
- Destroy DomU **Guest0**
- Guest0 has been removed from XEN domain list

Video: <https://youtu.be/NLmKTpCSI78>



```
U-Boot 2022.01 (Sep 20 2022 - 06:35:33 +0000)

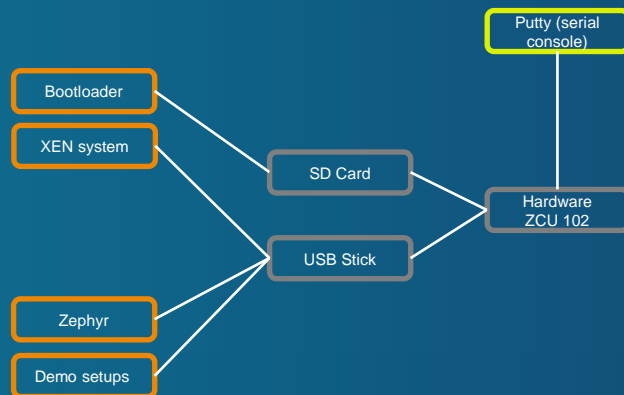
CPU:      ZynqMP
Silicon:  v3
Model:    ZynqMP ZCU102 Rev1.0
Board:    Xilinx ZynqMP
DRAM:     4 GiB
PMUFW:    v1.1
PMUFW no permission to change config object
EL Level: EL2
Chip ID:  zu9eg
NAND:     0 MiB
MMC:      mmc@ff170000: 0
Loading Environment from FAT... *** Warning - some problems detected reading environment; recovered successfully OK
In:       serial
Out:      serial
Err:      serial
Net:      FEC: can't find phy-handle

ZYNQ GEM: ff0e0000, mdio bus ff0e0000, phyaddr 12, interface rgmii-id
eth0: ethernet@ff0e0000
scanning bus for devices...
SATA link 0 timeout.
SATA link 1 timeout.
AHCI 0001.0301 32 slots 2 ports 6 Gbps 0x3 impl SATA mode
flags: 64bit ncq pm clo only pmp fbss pio slum part ccc apst
starting USB...
Bus usb@fe200000: Register 2000440 NbrPorts 2
Starting the controller
USB XHCI 1.00
scanning bus usb@fe200000 for devices...
Warning: asix_eth MAC addresses don't match:
Address in ROM is          c4:a8:1d:6d:c9:f9
Address in environment is   fc:75:16:cf:64:93
7 USB Device(s) found
scanning usb for storage devices... 1 Storage Device(s) found
Hit any key to stop autoboot: 2
```

# Zephyr: DomU with simple Zephyr application (2 tasks), no additional devices

- End of booting **Domain-0**
- Starting "Zephyr" demo with Zephyr image
- Check list of started Domains
- Switch console to **DomZ** (Zephyr)
- Getting back console to **Domain-0** (XEN)
- Destroy DomU "DomZ"
- "DomZ" has been removed from XEN domain list

Video: <https://youtu.be/CBrFMDZJbJA>



```
U-Boot 2022.01 (Sep 20 2022 - 06:35:33 +0000)

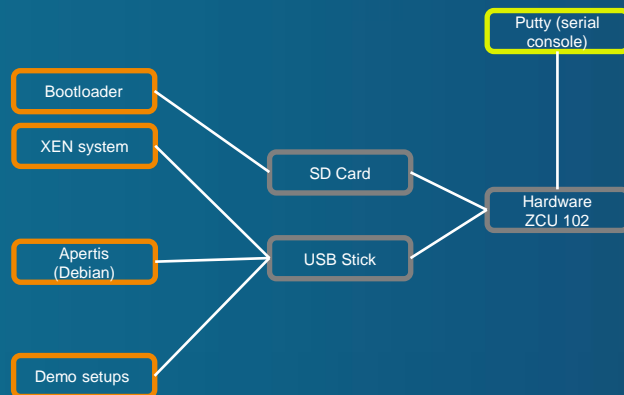
CPU:      ZynqMP
Silicon:  v3
Model:    ZynqMP ZCU102 Rev1.0
Board:    Xilinx ZynqMP
DRAM:     4 GiB
PMUFW:    v1.1
PMUFW no permission to change config object
EL Level: EL2
Chip ID:  zu9eg
NAND:     0 MiB
MMC:      mmc@ff170000: 0
Loading Environment from FAT... *** Warning - some problems detected reading environment; recovered successfully
OK
In:       serial
Out:      serial
Err:      serial
Net:      FEC: can't find phy-handle

ZYNQ GEM: ff0e0000, mdio bus ff0e0000, phyaddr 12, interface rgmii-id
eth0: ethernet@ff0e0000
scanning bus for devices...
SATA link 0 timeout.
SATA link 1 timeout.
AHCI 0001.0301 32 slots 2 ports 6 Gbps 0x3 impl SATA mode
flags: 64bit ncq pm clo only pmp fbss pio slum part ccc apst
starting USB...
Bus usb@fe200000: Register 2000440 NbrPorts 2
Starting the controller
USB XHCI 1.00
scanning bus usb@fe200000 for devices...
Warning: asix_eth MAC addresses don't match:
Address in ROM is          c4:a8:1d:6d:c9:f9
Address in environment is   fc:75:16:cf:64:93
7 USB Device(s) found
scanning usb for storage devices... 1 Storage Device(s) found
Hit any key to stop autoboot: 2
```

# Apertis: DomU with small Apertis system as ramdisk image, no additional devices

- End of booting Domain-0
- Starting "Apertis" demo with Apertis ramdisk image
- Check list of started Domains
- Switch console to **Apertis**
- No Network interfaces
- No block devices
- Getting back console to **Domain-0** (XEN)
- "Apertis" has been removed from XEN domain list

Video: <https://youtu.be/Jb6hgR9PG3Y>



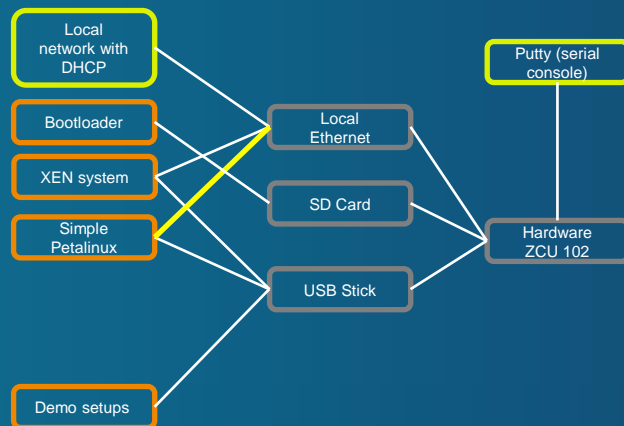
```
U-Boot 2022.01 (Sep 20 2022 - 06:35:33 +0000)

CPU:      ZynqMP
Silicon:  v3
Model:    ZynqMP ZCU102 Rev1.0
Board:    Xilinx ZynqMP
DRAM:     4 GiB
PMUFW:    v1.1
PMUFW no permission to change config object
EL Level: EL2
Chip ID:  zu9eg
NAND:     0 MiB
MMC:      mmc@ff170000: 0
Loading Environment from FAT... *** Warning - some problems detected reading environment; recovered successfully
OK
In:       serial
Out:      serial
Err:      serial
Net:      FEC: can't find phy-handle

ZYNQ GEM: ff0e0000, mdio bus ff0e0000, phyaddr 12, interface rgmii-id
eth0: ethernet@ff0e0000
scanning bus for devices...
SATA link 0 timeout.
SATA link 1 timeout.
AHCI 0001.0301 32 slots 2 ports 6 Gbps 0x3 impl SATA mode
flags: 64bit ncq pm clo only pmp fbss pio slum part ccc apst
starting USB...
Bus usb@fe200000: Register 2000440 NbrPorts 2
Starting the controller
USB XHCI 1.00
scanning bus usb@fe200000 for devices...
Warning: asix_eth MAC addresses don't match:
Address in ROM is      c4:a8:1d:6d:c9:f9
Address in environment is fc:75:16:cf:64:93
7 USB Device(s) found
scanning usb for storage devices... 1 Storage Device(s) found
Hit any key to stop autoboot: 2
```

# Paravirtualized network: DomU with Petalinux as ramdisk image, additional NET interface

- End of booting Domain-0
- Check Network Connection at **Domain-0**
- Create a network bridge to connect DomU **Guest0**
- Starting Petalinux ramdisk image as **Guest0** with paravirtualized network setup
- Switch console to **Guest0**
- Check Network Connection at **Guest0**
- **Guest0** (192.168.1.94) tries to ping **Domain-0** (192.168.1.98)
- **Guest0** has also connection to internet (google.de)
- **Guest0** can access **Domain-0**(192.168.1.98) via ssh connection
- Getting back console to **Domain-0** (XEN)
- **Domain-0** can access **Guest0** (192.168.1.94) via ssh connection
- **Guest0** is not destroyed, but initiates a normal shutdown.
- **Guest0** has been removed from XEN domain list



Video: <https://youtu.be/v2WtPtryPrc>

```
U-Boot 2022.01 (Sep 20 2022 - 06:35:33 +0000)

CPU:      ZynqMP
Silicon:  v3
Model:    ZynqMP ZCU102 Rev1.0
Board:    Xilinx ZynqMP
DRAM:     4 GiB
PMUFW:    v1.1
PMUFW no permission to change config object
EL Level: EL2
Chip ID:   zu9eg
NAND:      0 MiB
MMC:       mmc@ff170000: 0
Loading Environment from FAT... *** Warning - some problems detected reading environment; recovered successfully
OK
In:        serial
Out:       serial
Err:       serial
Net:       FEC: can't find phy-handle

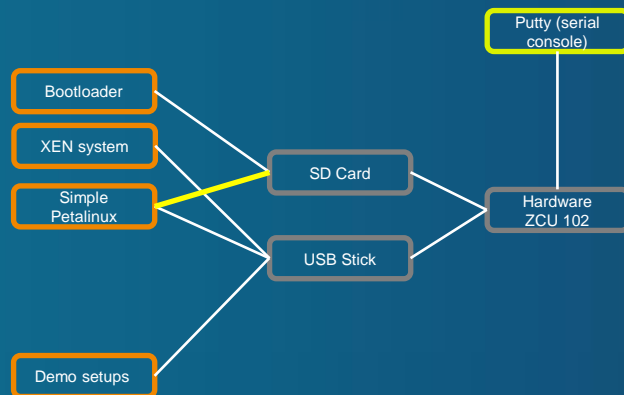
ZYNQ GEM: ff0e0000, mdio bus ff0e0000, phyaddr 12, interface rgmii-id
eth0: ethernet@ff0e0000
scanning bus for devices...
SATA link 0 timeout.
SATA link 1 timeout.
AHCI 0001.0301 32 slots 2 ports 6 Gbps 0x3 impl SATA mode
flags: 64bit ncq pm clo only pmp fbss pio slum part ccc apst
starting USB...
Bus usb@fe200000: Register 2000440 NbrPorts 2
Starting the controller
USB XHCI 1.00
scanning bus usb@fe200000 for devices...
Warning: asix_eth MAC addresses don't match:
Address in ROM is          c4:a8:1d:6d:c9:f9
Address in environment is   fc:75:16:cf:64:93
7 USB Device(s) found
scanning usb for storage devices... 1 Storage Device(s) found
Hit any key to stop autoboot: 2
```



# Paravirtualized block device: DomU with Petalinux, booted from paravirtualized block device

Video: <https://youtu.be/rUKYJevXQ-M>

- End of booting **Domain-0**
- Starting "Paravirtualized block device" demo with Petalinux booting from P3 of file system (USB-Stick)
- Check list of started Domains
- Switch console to **Guest0**
- /dev/xvda is the paravirtualized block device (P3 of USB stick)
- **Guest0** is not destroyed, but initiates a normal shutdown.



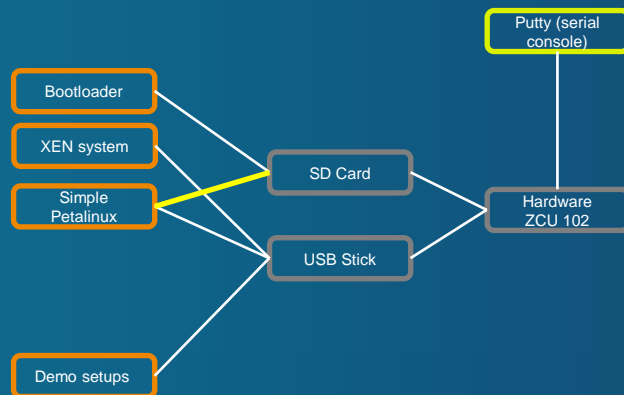
```
U-Boot 2022.01 (Sep 20 2022 - 06:35:33 +0000)

CPU:      ZynqMP
Silicon:  v3
Model:    ZynqMP ZCU102 Rev1.0
Board:    Xilinx ZynqMP
DRAM:     4 GiB
PMUFW:    v1.1
PMUFW no permission to change config object
EL Level: EL2
Chip ID:  zu9eg
NAND:     0 MiB
MMC:      mmc@ff170000: 0
Loading Environment from FAT... *** Warning - some problems detected reading environment; recovered successfully
OK
In:       serial
Out:      serial
Err:      serial
Net:      FEC: can't find phy-handle

ZYNQ GEM: ff0e0000, mdio bus ff0e0000, phyaddr 12, interface rgmii-id
eth0: ethernet@ff0e0000
scanning bus for devices...
SATA link 0 timeout.
SATA link 1 timeout.
AHCI 0001.0301 32 slots 2 ports 6 Gbps 0x3 impl SATA mode
flags: 64bit ncq pm clo only pmp fbss pio slum part ccc apst
starting USB...
Bus usb@fe200000: Register 2000440 NbrPorts 2
Starting the controller
USB XHCI 1.00
scanning bus usb@fe200000 for devices...
Warning: asix_eth MAC addresses don't match:
Address in ROM is      c4:a8:1d:6d:c9:f9
Address in environment is fc:75:16:cf:64:93
7 USB Device(s) found
scanning usb for storage devices... 1 Storage Device(s) found
Hit any key to stop autoboot: 2
```

# Passthrough of SD card controller: DomU with Petalinux as ramdisk image, additional block device

- Interrupt the automatic boot process at bootloader
- Configure passthrough of SD card device as "passthrough"
- Booting with XEN and **Domain-0**
- /dev/mmcblk0 (SD card) is not assigned to **Domain-0**
- Starting Petalinux ramdisk image as **Guest0** with passthrough configuration of SD card device
- Switch console to **Guest0**
- /dev/mmcblk0 is the passed through SD card device and keep only the bootloader
- Try to mount P1 of SD card device and have a look
- **Guest0** is not destroyed, but initiates a normal shutdown.



Video: <https://youtu.be/YXHfr8yFzy4>

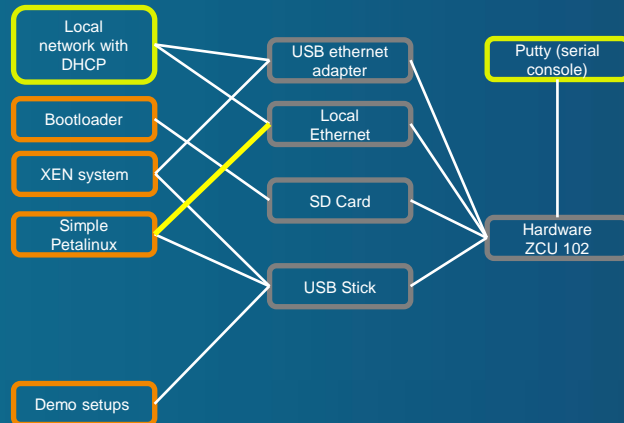
```
U-Boot 2022.01 (Sep 20 2022 - 06:35:33 +0000)

CPU:   ZynqMP
Silicon: v3
Model: ZynqMP ZCU102 Rev1.0
Board: Xilinx ZynqMP
DRAM:  4 GiB
PMUFW: v1.1
PMUFW no permission to change config object
EL Level: EL2
Chip ID: zu9eg
NAND:  0 MiB
MMC:   mmc@ff170000: 0
Loading Environment from FAT... *** Warning - some problems detected reading environment; recovered successfully
OK
In:    serial
Out:   serial
Err:   serial
Net:   FEC: can't find phy-handle

ZYNQ GEM: ff0e0000, mdio bus ff0e0000, phyaddr 12, interface rgmii-id
eth0: ethernet@ff0e0000
scanning bus for devices...
SATA link 0 timeout.
SATA link 1 timeout.
AHCI 0001.0301 32 slots 2 ports 6 Gbps 0x3 impl SATA mode
flags: 64bit ncq pm clo only pmp fbss pio slum part ccc apst
starting USB...
Bus usb@fe200000: Register 2000440 NbrPorts 2
Starting the controller
USB XHCI 1.00
scanning bus usb@fe200000 for devices...
Warning: asix_eth MAC addresses don't match:
Address in ROM is      c4:a8:1d:6d:c9:f9
Address in environment is fc:75:16:cf:64:93
7 USB Device(s) found
scanning usb for storage devices... 1 Storage Device(s) found
Hit any key to stop autoboot: 2
```

# Passthrough of ethernet controller: DomU with Petalinux as ramdisk image, additional network interface

- Interrupt the automatic boot process at bootloader
- Configure passthrough of internal ethernet controller as "passthrough"
- Booting with XEN and **Domain-0**
- Check Network Connection at **Domain-0** with used USB-Ethernet adapter
- Starting Petalinux ramdisk image as **Guest0** with passthrough configuration of internal ethernet controller
- Switch console to **Guest0**
- Check network connection at **Guest0**
- **Guest0** has connection to internet (google.de)
- Getting back console to **Domain-0** (XEN)
- **Domain-0** (192.168.1.81) tries to ping **Guest0** (192.168.1.95)
- **Domain-0** can access **Guest0** (192.168.1.95) via ssh connection
- Guest0 exits from ssh connection, getting back console to **Domain-0**
- Switch console to **Guest0**
- **Guest0** can access **Domain-0** (192.168.1.81) via ssh connection



Video: <https://youtu.be/hAwUO2-O79w>

```
U-Boot 2022.01 (Sep 20 2022 - 06:35:33 +0000)

CPU:      ZynqMP
Silicon:  v3
Model:    ZynqMP ZCU102 Rev1.0
Board:    Xilinx ZynqMP
DRAM:     4 GiB
PMUFW:    v1.1
PMUFW no permission to change config object
EL Level: EL2
Chip ID:  Zu9eg
NAND:     0 MiB
MMC:      mmc@ff170000: 0
Loading Environment from FAT... *** Warning - some problems detected reading environment; recovered successfully
OK
In:       serial
Out:      serial
Err:      serial
Net:      FEC: can't find phy-handle

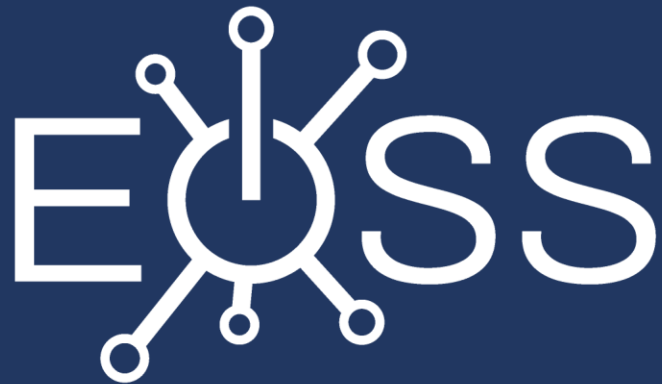
ZYNQ GEM: ff0e0000, mdio bus ff0e0000, phyaddr 12, interface rgmii-id
eth0: ethernet@ff0e0000
scanning bus for devices...
SATA link 0 timeout.
SATA link 1 timeout.
AHCI 0001.0301 32 slots 2 ports 6 Gbps 0x3 impl SATA mode
flags: 64bit ncq pm clo only pmp fbss pio slum part ccc apst
starting USB...
Bus usb@fe200000: Register 2000440 NbrPorts 2
Starting the controller
USB XHCI 1.00
scanning bus usb@fe200000 for devices...
Warning: asix_eth MAC addresses don't match:
Address in ROM is      c4:a8:1d:6d:c9:f9
Address in environment is fc:75:16:cf:64:93
7 USB Device(s) found
scanning usb for storage devices... 1 Storage Device(s) found
Hit any key to stop autoboot: 2
```



## Getting involved...

- Join main technical and weekly calls of interest:
  - Main Technical List: [devel@lists.elisa.tech](mailto:devel@lists.elisa.tech)
  - Safety Architecture Workgroup: [safety-architecture@lists.elisa.tech](mailto:safety-architecture@lists.elisa.tech)
  - Open-Source Engineering Process WG [osep@lists.elisa.tech](mailto:osep@lists.elisa.tech)
  - Linux Features for Safety-Critical Systems WG: [linux-features@lists.elisa.tech](mailto:linux-features@lists.elisa.tech)
  - Medical Devices Workgroup: [medical-devices@lists.elisa.tech](mailto:medical-devices@lists.elisa.tech)
  - Automotive Workgroup: [automotive@lists.elisa.tech](mailto:automotive@lists.elisa.tech)
  - Systems Workgroup: [systems@lists.elisa.tech](mailto:systems@lists.elisa.tech)
  - (Full list at: <https://lists.elisa.tech/g/linux-features/subgroups>)
- Contribute content, review materials and add your comments to:
  - ELISA Technical Community Google Drive:  
<https://drive.google.com/open?id=1Y6Uwqt5VEDEZjpRe0CBClibdtXPgDwlG>
  - ELISA github repository: <https://github.com/elisa-tech/workgroups>
  - ELISA github issue tracker: <https://github.com/elisa-tech/workgroups/issues>
  - “Final location” for (Architecture/Process/...) Documentation on kernel:  
<https://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git/tree/Documentation>

THANK YOU!



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